

Phosphorus is present in plants in both the inorganic, as orthophosphate, and organic forms. The organic forms are compounds in which the orthophosphate is esterified with hydroxyl groups of sugars and alcohols, or bound by a pyrophosphate to another phosphate group (4). These organic forms are especially important for energy storage and transfer processes. In P deficient plants, the inorganic P concentration is depressed much more than the organic P concentration. This reduction is accompanied by reduced protein synthesis and reduced vegetative growth, particularly root growth. Phosphorus is relatively mobile in plants and, under conditions of P deficiency, is translocated from the older plant tissues to the actively growing tissues or to plant parts that serve a storage function. Phosphorus deficiency symptoms are generally expressed in the older leaves as a darkish green color from an enhanced anthocyanin production.

Plant nutrient analysis is used to determine the nutritional status of the plant, reflecting the nutrient availability in the soil. Important factors influencing the nutrient concentration and uptake are plant age, plant parts or tissues analyzed, and the availability of other nutrients. Petioles from the fourth leaf from the growing tip are generally used as indicators of nutrient status in potato plants. Critical nutrient ranges for N, P, K, Zn, and Mn are available for use in the Pacific Northwest growing areas (2). Most of these data for potatoes were developed by relating nutrient concentrations during plant growth to final tuber yields. Recent studies show that N fertilizer efficiencies and crop yields are improved if the N fertilizer is applied according to crop growth rates (7, 8). In that study petiole $\text{NO}_3\text{-N}$ concentrations were used to monitor the plant's N nutritional status. This project is an attempt to apply some of the same concepts and principles to the P nutrition of this crop. The objectives of this report are to relate the petiole P concentrations to the P and dry matter distribution patterns during potato plant development and to relate these changes to final tuber yields.

METHODS AND MATERIALS

The results presented here for the Russet Burbank potato plant come from two main sources: potato nutrient survey data and replicated field experiments, conducted from 1976 to 1982. The data sets include samples from all the major potato production areas in Idaho. Data from the surveys were only used to show the nutrient relationships within the plant itself, whereas data from the field experiments were used to develop the growth, yield, and nutritional rate relationships.

1/ Proceedings, 34th Annual N. W. Fertilizer Conference, Portland, Oregon, July 12-13, 1983

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Cultural and fertilization practices are not available for the survey sites, however, standard practices were followed in all the field experiments (5). The P treatments were established by broadcast applications of concentrated superphosphate (0-45-0) followed by either plowing or disking prior to planting. Sprinkler irrigations were scheduled according to tensiometers placed in the row at the seed-piece depth, allowing a 40 to 50% depletion of available soil water between irrigations. Each experiment contained four or five replications.

The growth analysis was started at early tuber set by determining the dry weight of whole plants in a 5-foot row section from each plot at about 14-day intervals until vine removal prior to the final tuber harvest. Easily recoverable roots and all tubers were washed before determining fresh weights. Leaf area indexes were determined on selected treatments. All plant parts were dried, weighed, ground to pass a 40-mesh sieve, and analyzed for total P (3). Petioles from the most recent fully expanded matured leaf (fourth from growing tip) were also taken at the same time for total P (3) and soluble PO_4 -P analysis (1). Final tuber yields were measured by harvesting two rows, each 30 to 40 feet long, from each plot. Tubers were evaluated for specific gravity, uniformity, and size distribution.

RESULTS

Representative effects of P nutrition on relative tuber yields and petiole PO_4 -P concentrations, and the relative P distribution in the total plant and tubers are shown in Fig. 1 and 2, respectively. The soil test P concentration was considered to be adequate for the high-P treatment and deficient for the low-P treatment (5).

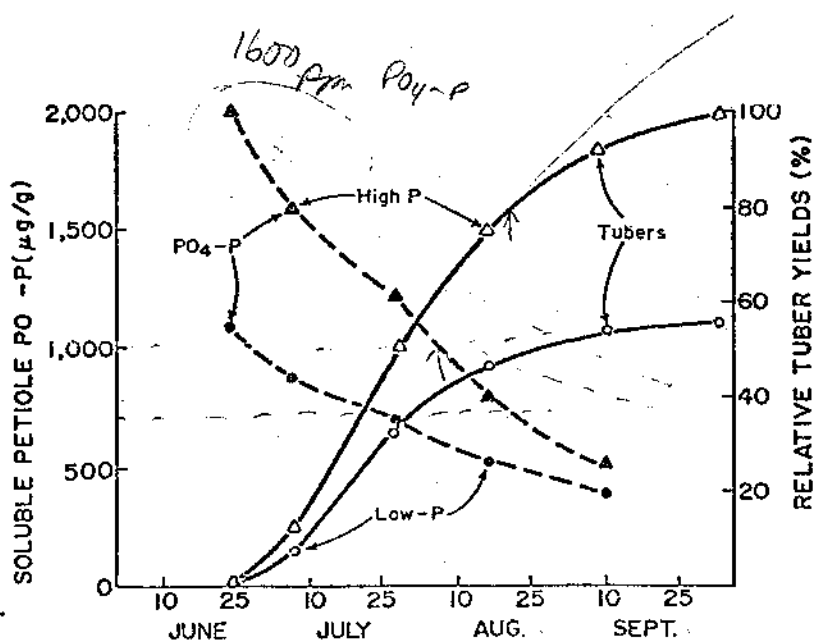


Fig. 1. The relative increase in tuber yields and decrease in soluble petiole PO_4 -P concentrations for a low-P and high-P treatment.

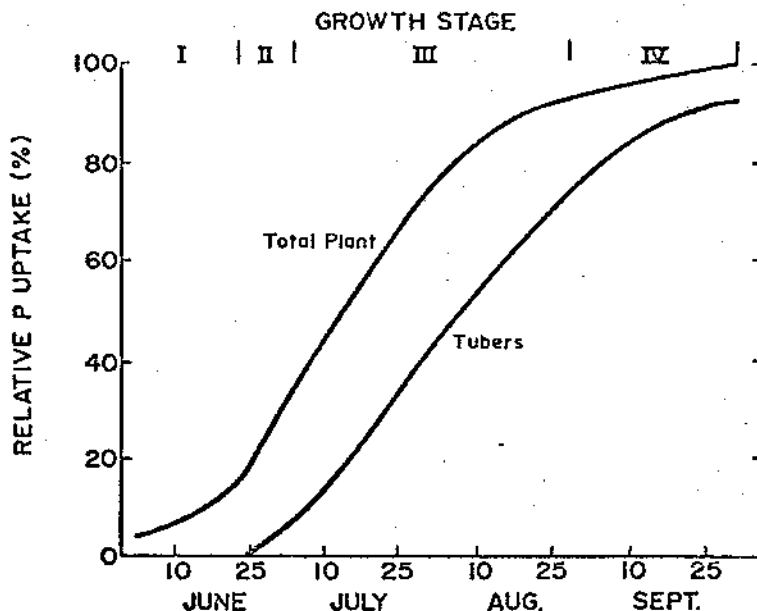


Fig. 2. The relative distribution of P in potato plants during the growing season.

Tuber growth rates and the duration of tuber growth were significantly lower in the low-P compared to the high-P treatment. By the end of August, tuber yields were near their maximum in the low-P treatment, while only at about 85% of their maximum in the high-P treatment. Petiole PO_4 -P concentrations dropped rapidly in both treatments, with the decline rate for the high-P being about two-fold that of the Low-P treatment. Petiole PO_4 -P concentrations would be considered adequate during early tuber set for the high-P but not for the low-P treatment (2, 7).

The relative total P uptake increased rapidly after the start of growth stage II (tuber initiation) and was 95% of maximum by the end of growth stage III (tuber growth) (Fig. 2). The increase in P content of the tubers nearly paralleled total plant P uptake until about August 15, after which P was translocated from the vegetative tissues into the tubers during IV (maturation). The relative P uptake distributions for the high-P and low-P treatments were similar during the season.

The soluble petiole PO_4 -P concentrations were curvilinearly related to the total P concentrations in the potato tops during the growing season (Fig. 3). Concentrations in the plant samples were high in the early samplings, decreasing to lower concentrations as the growing season progressed. The slope of this relationship was about 2:1 up to 0.3% P in the tops and above that it was close to 1:1.

Seeds and potato tubers become major sinks for P during the plant's growth and development. Phosphorus was observed to be translocated from the plant's vegetative portions to the tubers during part of growth stage III and during all the IV growth stage. An estimate of the P balance between tuber

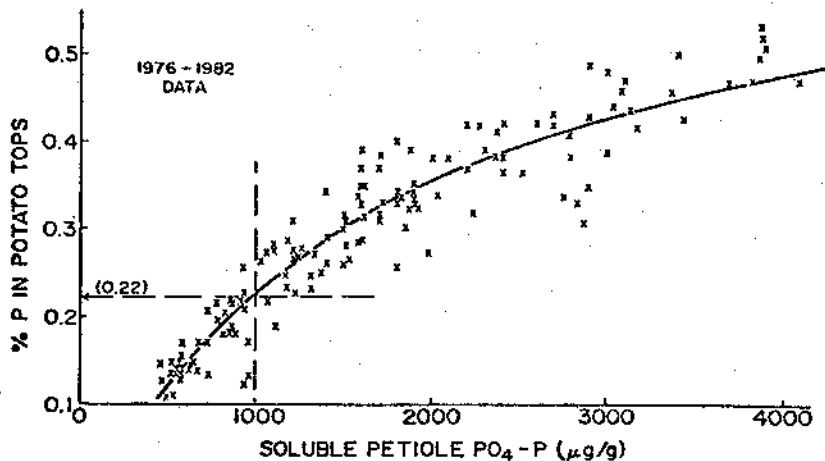


Fig. 3. The relationship between soluble petiole $\text{PO}_4\text{-P}$ and the total P concentrations in potato tops.

growth needs and total plant uptake is provided by the ratio of the change in total plant P uptake divided by the change in tuber P content on an area basis between two consecutive samplings. Ratios greater than one indicate that more P was being taken up by the plant than utilized by the tubers, while a ratio less than one indicates that more P was going into the tubers than being taken up by the plant. In this latter case P is assumed to be translocated into the tubers from the rest of the plant. This ratio was then compared with the average P concentration of the potato tops during the same sampling interval (Fig. 4). The dividing line separating data points with ratios less than one from those greater than one is at about 0.22% P in the potato tops.

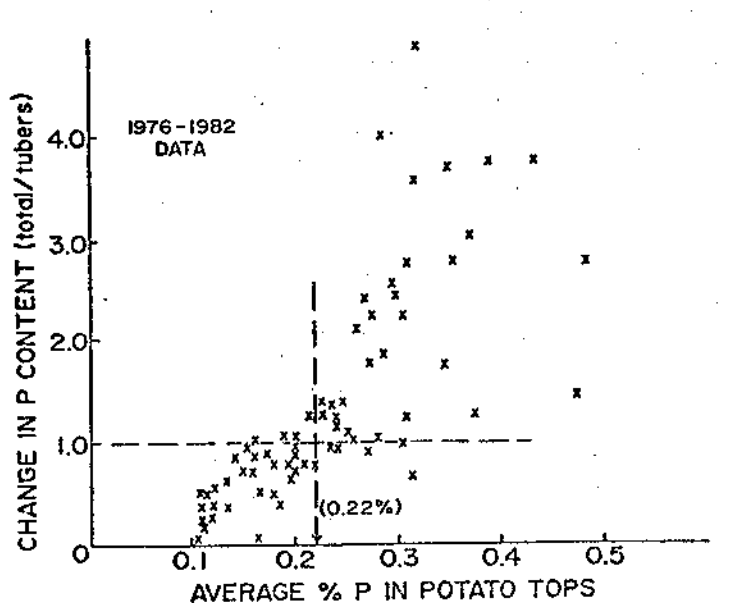


Fig. 4. The relationship between the average total P concentration of potato tops and the ratio of the change in the P content of the whole plant divided by the change in the P content of the tubers between two consecutive samplings.

The total P concentration of the potato tops was also related to the total P concentration of the leaves not showing any visible signs of senescence at sampling, "active leaves" (Fig. 5). Above about 0.16% P in the tops this relationship was linear, while below that the data points are scattered. This occurred late in the growing season when many of the "active leaves" were growing on secondary and tertiary branches and their P concentrations were high compared to the P concentration of the total top. Leaf area indexes were decreasing and were generally less than three when this occurred.

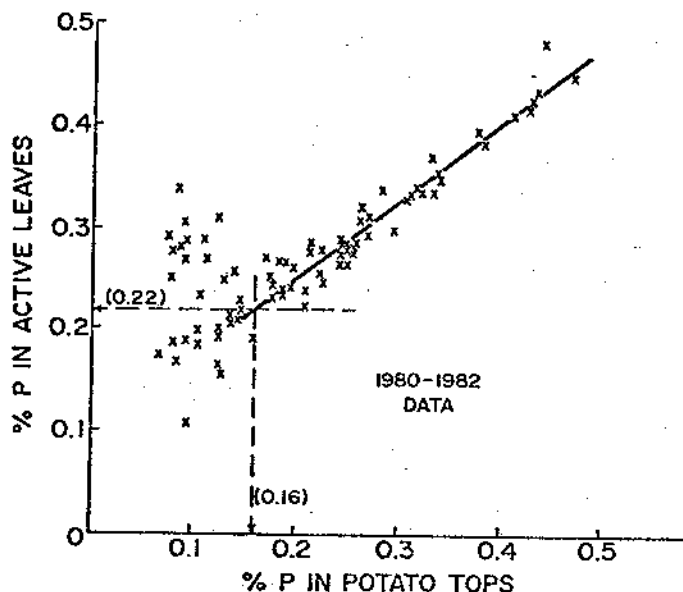


Fig. 5. The relationship between the total P concentration of potato tops and the total P concentration of the active leaves.

The P concentration of the "active leaves" was compared with the ratio of the change in total plant dry weight divided by the change in tuber dry weight on an area basis between consecutive samplings (Fig. 6). The average leaf P concentration during the sampling interval and only the data having a leaf area index of three or more were used. This relationship indicates that dry matter production rates sufficient for tuber growth needs require leaf P concentrations to be greater than 0.22% P. Ratios less than one could also occur when leaf P concentrations were above 0.22% from smaller active leaf areas, other nutrient deficiencies, or unfavorable environmental conditions.

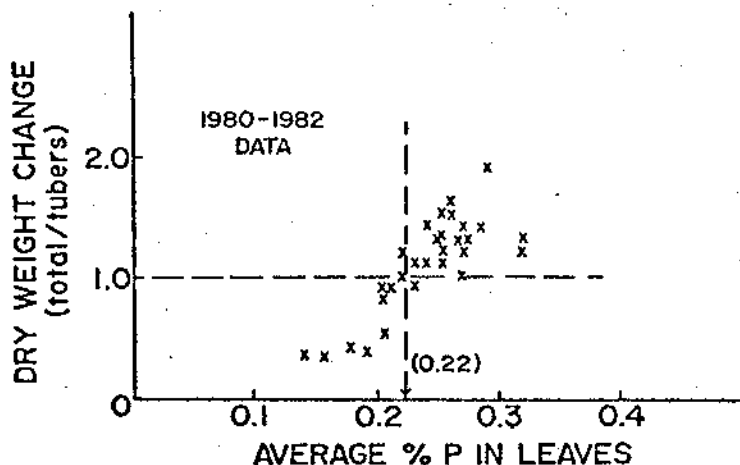


Fig. 6. The relationship between the average total P concentration of the active leaves and the ratio of the change in the dry weight of the whole plant divided by the change in the dry weight of the tubers between two consecutive samplings. Data points are for those plants with a leaf area index greater than three.

DISCUSSION AND SUMMARY

Early season P deficiency reduces both tuber growth rates and their durations to give lower tuber yields. Developing potato tubers appear to be such a dominant sink that both photosynthates and mobile nutrients are translocated from the other parts of the plant to maintain tuber growth rates when they are limiting. Tubers sufficiently supplied with P will contain about 0.042 lbs P/cwt. A tuber growth rate of 7 cwt/day-acre requires a plant P uptake rate of at least 0.29 lbs P/day-acre to satisfy only the tuber growth yields. Even the high-P treatment (Fig. 1) did not have P uptake rate greater than this after August 1. The information contained in Figs. 4, 5, and 6, and the total P concentration of the tops for the high-P treatment (not shown), showed that it contained only enough excess P in the vegetation to maintain its dry matter production in excess of tuber needs for only 12 days after August 1. This would correspond to a decrease in petiole PO_4 -P concentrations from about 1000 to 700 $\mu\text{g/g}$ (Fig. 3).

These data suggest that final tuber yields may be related to the number of days during which adequate P concentrations are maintained in the tops, providing other production factors are not limiting. The number of days after tuber set that the potato tops contained at least 0.22% P were compared with the final tuber yields in cases where other known factors were not limiting growth nor yields (Fig. 7). Tuber yields increased about 5 cwt/acre for each day the P concentration of the potato tops were greater than 0.22% after tuber set. The number of days with adequate P in the tops would be a function of the total P content of the plants at tuber set, and the tuber growth and total P uptake rates after tuber set.

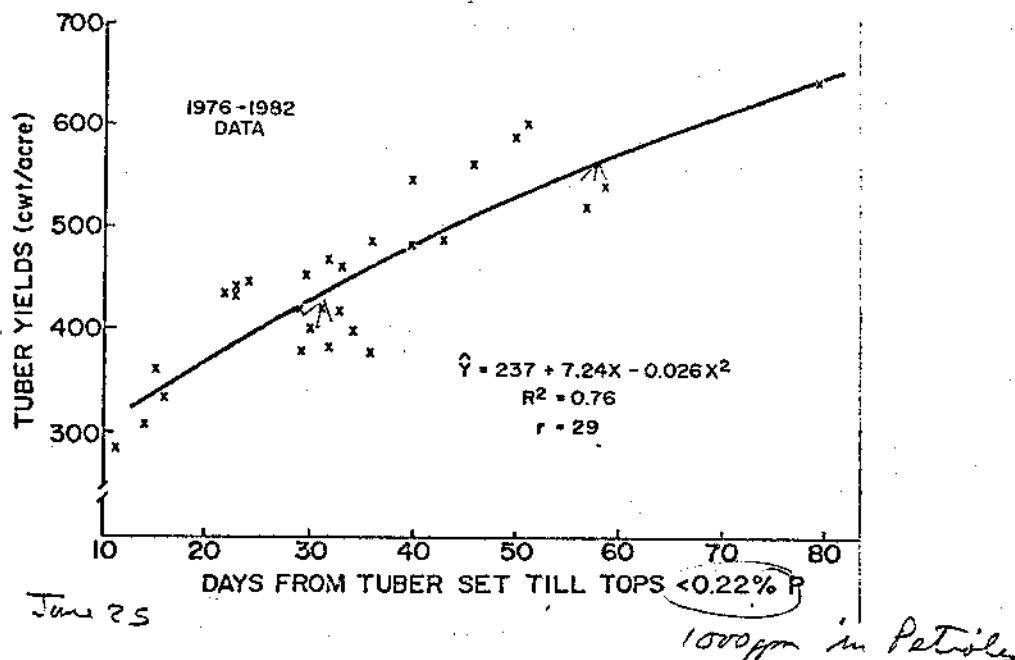


Fig. 7. The relationship between the number of days after tuber set for which the P concentration of the tops was greater than 0.22% P and the final tuber yields.

The significance of this study is indicated by examining the petiole PO_4 -P concentrations from 81 potato fields sampled from 1977 to 1981. There were 42 fields that had less than 1000 $\mu\text{g/g}$ PO_4 -P in their petioles after August 15-20. Preliminary data also indicate that plant P concentrations during tuber growth might be a factor in the susceptibility to infection by Verticillium dahliae (personal communications, J. R. Davis, Aberdeen, Idaho). Additional studies are needed to evaluate the potential of maintaining P concentrations in the plant throughout the season by P fertilizer applications during plant growth and the suitability of various materials for this practice.

The petiole PO_4 -P concentration is a good indicator of the P status of potato plants according to the data presented here. Concentrations of 1000 $\mu\text{g/g}$ PO_4 -P or greater indicated that the total plant P uptake rate was sufficient for both the vegetative and tuber growth needs.

Table 1. The relationship between the total P and soluble $\text{PO}_4\text{-P}$ in the fourth potato petiole to the total P uptake and dry matter production rates expressed as the ratio total plant:tuber.

4th petiole		Ratio (Total/Tuber)	
Total P	Soluble $\text{PO}_4\text{-P}$	P Uptake	Dry matter Production
(%)	($\mu\text{g/g}$)		
<0.17	<700	<1	<1
	700-1000	<1	>1
>0.22	>1000	>1	>1

Phosphorus concentrations less than 1000 $\mu\text{g/g}$ indicated that the tubers required more P than was being taken up by the plant, decreasing the P concentration in the leaves, and eventually limiting the dry matter production capability. An excellent relationship between total P and soluble $\text{PO}_4\text{-P}$ in the petiole indicates that total P can also be used (Fig. 8) as a monitoring tool.

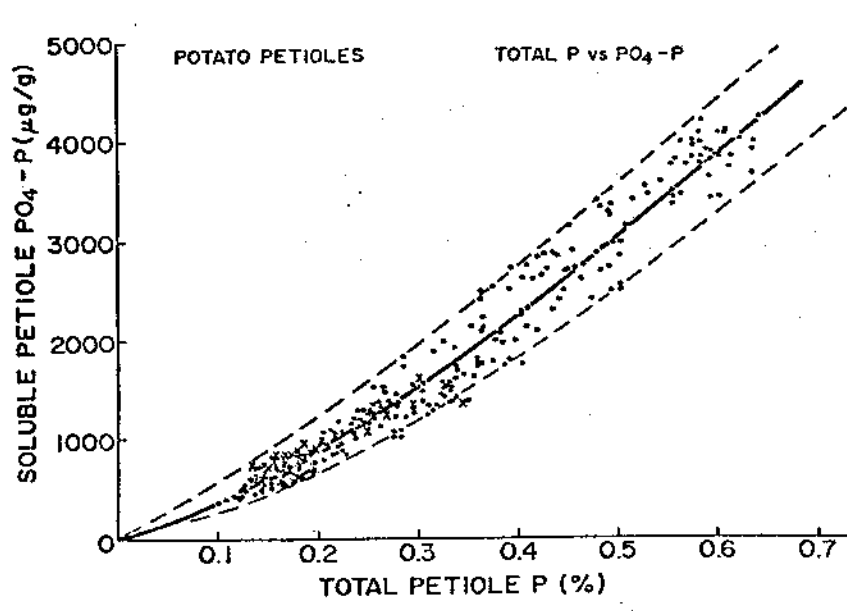


Fig. 8. The relationship between the total P and soluble $\text{PO}_4\text{-P}$ concentrations of potato petioles. Data were also obtained from Painter and McDole (1978).

ACKNOWLEDGEMENTS

Appreciation is extended to S. E. Crothers, J. L. Johnson, and to the other individuals who provided technical assistance and land in obtaining the data presented in this paper.

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